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cir #39

7-20-06

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—Circular 39 (Second Edition).

GIFFORD PINCHOT, Forester.

EXPERIMENTS ON THE STRENGTH OF TREATED TIMBER.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Forest Service,
Washington, D. C., January 17, 1908.

Sir: I have the honor to transmit herewith the revision of a paper entitled "Experiments on the Strength of Treated Timber," by Dr. W. Kendrick Hatt, Civil Engineer in the Forest Service, and to recommend its publication as Circular 39 (Second Edition) of the Forest Service. All materials used in the experiments were furnished free of charge. The preserving plant, which was designed by Mr. W. W. Curtis, of Chicago, was loaned by the Ayer & Lord Tie Company and the Allis-Chalmers Company, of Chicago, the planer and saw by the Fay & Egan Company, of Cincinnati, and the motors for driving the machinery by the Western Electric Company, of New York City. The creosote was furnished by the Chatfield Manufacturing Company, of Cincinnati, and the zinc chlorid by the General Chemical Company, of Chicago, and the ties by the Atchison, Topeka and Santa Fe Railway Company. The experiments to determine the strength of the material were made in cooperation with Purdue University, Lafayette, Ind.

Very respectfully,

Gifford Pinchot,
Forester.

Hon. James Wilson,
Secretary of Agriculture.

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EXPERIMENTS ON THE STRENGTH OF TREATED TIMBER.

INTRODUCTION.

In 1904 the Forest Service erected a small plant on the grounds of the St. Louis Exposition for investigating methods of preserving timber and for studying the influence of preservative processes upon the strength of wood.

The plan for the timber tests was drawn up by Dr. Hermann von Schrenk and the author.

At the close of the exposition the timber-testing laboratory was removed to the timber-testing station of the Forest Service at Purdue University, Lafayette, Ind., where the mechanical tests were completed. In all, 6,272 tests were made.

A complete and detailed presentation of all pertinent data obtained would necessarily be of considerable magnitude. It is thought best, therefore, to publish at present only a brief summary of the experiments and their results, for the use of engineers and of those connected with the wood-preserving industry.

DESCRIPTION OF PLANT.

The plant consisted of two distinct parts—a timber-preserving plant and a timber-testing laboratory.

The preserving plant was in essentials similar to those in commercial use, and consisted of a high-pressure impregnating cylinder, capable of withstanding at least 600 pounds pressure per square inch, with the necessary vacuum and pressure pumps, storage cylinders, and reservoirs.

The timber-testing laboratory included one impact machine and a 30,000-pound Olsen testing machine. A power saw and planer were installed with the timber-testing machines, so that all test pieces were cut and planed on the ground.

The testing laboratory was under the charge of Mr. H. D. Hartley, Engineer of Timber Tests, Forest Service, and was supervised by the author. The preserving plant was in charge of an experienced timber-treating engineer and was supervised by Dr. Hermann von Schrenk.

PLAN OF EXPERIMENTS.

In outlining the plan for these tests two divisions were made, dealing respectively with the effect on the strength of timber of the preliminary processes of steaming, superheating, vacuum, etc., commonly employed in the preservation of wood, and the effect of the preserving materials themselves.

The programme, therefore, naturally fell into two parts. Part 1 was carried out in advance of part 2. The tests were confined to sapwood, and were made on small pieces taken from the ties, and also on full-sized ties.

The effect of the preliminary processes was determined on both green and seasoned timber. Both green and seasoned timber were also used in determining the effect of preservatives. The preservative fluids included only creosote and zinc chlorid.

The material for the experiments was railroad ties 11 feet long. One 8-foot section of each tie was put through the particular treatment, and the untreated section, 3 feet long, was used for control test pieces.

TESTS OF SMALL PIECES.

From each tie 12 pieces were taken, 4 from the control section and 8 from the treated section. All of these pieces were 2 inches by 2 inches in cross section and 36 inches long, with one side parallel to the direction of the annual rings and the other at right angles to it. After the bending tests had been made on these pieces, smaller pieces, 2 inches by 2 inches in cross section and 4 inches long, were cut from their ends and used for the compression and shearing tests.

In any tie the test pieces were taken out according to the following sketch, variation being allowed only to secure clear pieces.

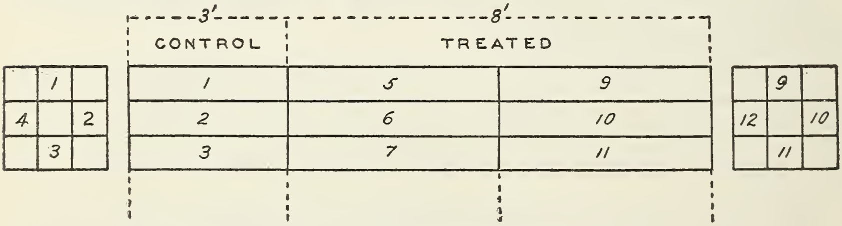

FIG. 1.—Manner of selecting test pieces from the tie.

The test pieces from each tie were marked consecutively from 1 to 12. The untreated pieces marked 1 and 2 were used for control-impact tests, and those marked 3 and 4 for control-static tests. The treated pieces marked 5 and 6 were used for impact tests, those marked 7 and 8 for static tests. The treated pieces marked from 9 to 12 were similarly tested, but were resoaked, if necessary, to bring them back to the degree of moisture found in the control pieces. Ordinarily the steaming process did not decrease the moisture content of the wood, in which case tests on resoaked pieces were not required.

In part 2 of the programme the test pieces which had been subjected to the action of the preservative were numbered as above, except that a letter was used to indicate whether creosote or zinc chlorid was used. Only clear pieces were tested. Disturbance of the relations sought, due to knots and other irregularities, was thus avoided.

The experiments on any run were based on four ties marked *a*, *b*, *c*, and *d*, which yielded 36 test pieces per tie, as follows:

Control:
- 2 impact—bending.
- 2 impact—compression parallel to grain.
- 2 static—bending.
- 2 static—compression parallel to grain.
- 2 static—compression at right angles to grain.
- 2 static—shearing.

Treated:
- 2 impact—bending.
- 2 impact—compression parallel to grain.
- 2 static—bending.
- 2 static—compression parallel to grain.
- 2 static—compression at right angles to grain.
- 2 static—shearing.

Treated and resoaked:
- 2 impact—bending.
- 2 impact—compression parallel to grain.
- 2 static—bending.
- 2 static—compression parallel to grain.
- 2 static—compression at right angles to grain.
- 2 static—shearing.

Not all of the resoaked pieces were necessarily tested, as explained above.

TESTS OF FULL-SIZED TIES.

In addition to the tests on small pieces, the strength of full-sized ties in bending and in compression, both parallel and at right angles to grain, was obtained, as well as the capacity of the wood to hold a spike. The ties used were 8 feet long. The entire tie was treated and afterwards tested in full size. In the bending tests under a static load the ties were supported on a span of 80 inches and loaded at the third points of the span. Short sections of the ties were used for tests to determine the resistance against compression parallel to grain, against compression at right angles to grain (which is similar to that produced on a tie by the base of a rail), and against the force withdrawing a spike. In the tests of compression at right angles to grain the width of the tool equaled that of the base of an 80-pound rail of the standard of the American Society of Civil Engineers. The force necessary to cause the yielding of the wood was measured. Both screw spikes and common spikes were driven into the tie, and the force necessary to pull them out directly along their length was measured. Any common spike was driven but once, since it was found that the resistance against pulling diminished when the spike was redriven into new wood.

The weight of the tie before treating, after treating, and at the time of test was determined. The physical characteristics of the wood, such as per cent of sap, rate of growth, shakes, knots, and moisture content, were also recorded.

Impact tests were made on certain of the full-sized ties. In general it was found that the influence of the various factors may be determined by both static and impact tests.[a] An exception in the case of Burnettized wood is noted later.

TREATMENTS BEFORE TESTING.

A complete schedule of the various treatments to which the material was subjected preliminary to the tests is given below. Each treatment was administered to one or more runs of 4 ties each.

(A) 184 6-inch by 8-inch Hewed Loblolly Pine Ties from Texas—Green.

The tests were made on small, clear pieces taken in the manner before described.

(1) One hundred and forty-eight ties, from which pieces were tested immediately after being subjected to the following treatments:

Series 25, 26. Steamed at 0 pound for 4 hours.
104. Steamed at 10 pounds for 4 hours.
7, 37. Steamed at 20 pounds for 4 hours.
3, 116. Steamed at 30 pounds for 4 hours.
4, 117. Steamed at 40 pounds for 4 hours.
5, 23. Steamed at 50 pounds for 4 hours.
118. Steamed at 100 pounds for 4 hours.
1. Steamed at 20 pounds for 1 hour.
105. Steamed at 20 pounds for 2 hours.
2. Steamed at 20 pounds for 3 hours.
7, 37. Steamed at 20 pounds for 4 hours.
21. Steamed at 20 pounds for 5 hours.
22. Steamed at 20 pounds for 6 hours.
6, 119. Steamed at 20 pounds for 10 hours.
121. Steamed at 20 pounds for 20 hours.
15. Steamed at 20 pounds for 4 hours. Treated with a 2½ per cent solution of zinc chlorid.
18. Steamed at 20 pounds for 4 hours. Treated with a 10 per cent solution of zinc chlorid.
27, 29, 32, 103. Steamed at 20 pounds for 4 hours. Treated with 20.02 pounds creosote per cubic foot.
120. No treatment. A series to show the variation in test pieces cut from the same tie.

The results of these treatments are shown in Table 3.

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[a] Recent tests made by the Forest Service, however, show that the effect of heat treatment is best determined by impact tests.

(2) Thirty-six ties treated and allowed to air dry before testing:

Series 7A. Steamed at 20 pounds for 4 hours.
3A. Steamed at 30 pounds for 4 hours.
4A. Steamed at 40 pounds for 4 hours.
5A. Steamed at 50 pounds for 4 hours.
15A. Steamed at 20 pounds for 4 hours. Treated with a 2½ per cent solution of zinc chlorid.
16A. Steamed at 20 pounds for 4 hours. Treated with a 3½ per cent solution of zinc chlorid.
17A. Steamed at 20 pounds for 4 hours. Treated with a 5 per cent solution of zinc chlorid.
18A. Steamed at 20 pounds for 4 hours. Treated with a 10 per cent solution of zinc chlorid.
27A. Steamed at 20 pounds for 4 hours. Treated with 25.4 pounds creosote per cubic foot.

The results are shown in Tables 4 and 5.

The preserving fluids in both 1 and 2 were injected under a pressure of 100 pounds per square inch, following a vacuum of 28 inches for one hour in the case of a zinc-chlorid treatment and of 28 inches for two hours in the case of creosote treatment. The temperature of the creosote was 150° F.

(B) 20 6-inch by 8-inch Hewed Loblolly Pine Ties from Texas—Seasoned.

The tests were made immediately after treatment on small, clear test pieces taken from the ties.

The ties were treated as follows:

Series 36. Steamed with exhaust steam for 4 hours.
24. Steamed at 50 pounds for 4 hours.
30. Steamed at 20 pounds for 4 hours. Treated with 25.62 pounds creosote per cubic foot.
31, 108. No steaming. Treated with 21.18 and 19.20 pounds creosote per cubic foot, respectively.

The creosote was injected under the conditions described under A.

From these ties small test pieces were cut for tests in bending (static and impact), compression parallel to grain (static and impact), compression at right angles to grain (static), shear (static), and abrasion.

The results are shown in Table 6.

(C) 165 6-inch by 8-inch Hewed Loblolly Pine Ties from Texas—Seasoned.

The tests were made on full-sized ties, treated as follows:

Series 133A. Steamed at 10 pounds for 4 hours.
134A. Steamed at 20 pounds for 4 hours.
135A. Steamed at 30 pounds for 4 hours.
136A. Steamed at 40 pounds for 4 hours.
137A. Steamed at 50 pounds for 4 hours.
138A. Steamed at 20 pounds for 2 hours.

Series 139A. Steamed at 20 pounds for 6 hours.
140A. Steamed at 20 pounds for 10 hours.
141A. Steamed at 20 pounds for 4 hours. Treated with 28 pounds creosote per cubic foot.
142A. Steamed at 20 pounds for 4 hours. Treated with a 2½ per cent solution of zinc chlorid.
143A. No steaming or treatment.

The fluids were injected under the same conditions of pressure and vacuum as described under A.

The ties were above the average grade and contained but few defects. It was impossible to secure clear ties, but the large number averaged will practically eliminate the variation in results due to defects.

After treatment the ties were seasoned for eight months. The steamed ties reached their original moisture content, but the fiber of the creosoted ties had not seasoned to the same extent. They were then tested in full size as beams, to determine their resistance to the pressure corresponding to that of the base of the rail (compression at right angles to grain), and to determine their holding capacity for railway spikes, common and screw. The results are shown in Table 7.

(D) 97 Sawed Bridge Ties of Western Yellow Pine from New Mexico and Arizona—Partially Seasoned.

The ties were treated as follows:

Series 105. No steaming or treatment.
106. No steaming. Zinc chlorid, 2½ per cent solution.
107. Steamed 3 hours at 20 pounds. Zinc chlorid 2½ per cent.
108. No steaming. Creosote 11 pounds per cubic foot.
109. Steamed 3 hours at 20 pounds. Creosote 13 pounds per cubic foot.
110. Boiled in creosote for 2 hours at 220° F. Soaked in cold oil 3 hours.
111. Boiled in creosote for 2 hours at 275° F. Soaked in cold oil 1 hour.

In series 106, 107, 108, and 109 the preservatives were injected with the same vacuum and pressure described under A. The ties from Arizona were cut about 15 miles north of Flagstaff, Ariz., January, 1903, and were considered a good average of this class of material. The lot from New Mexico were cut in the vicinity of the Pecos River Forest Reserve about January, 1903, and were of much better quality than those from Arizona.

These ties were average bridge ties and were tested in full size eight months after treatment. They were first tested under impact and static bending. Small blocks were then sawed from various parts of the cross section to determine the strength of the wood clear of knots.

The results are shown in Table 8.

(E) 10 7-inch by 9-inch Sawed Loblolly Pine Ties from Eastern Texas—Seasoned.

A number of tests were made upon pieces cut from loblolly pine ties which had been treated at Somerville, Tex., by the Santa Fe Railway Company.

The process to which these ties were subjected is thus described by Mr. E. O. Faulkner, of the Santa Fe Railway:

1. Material: Seasoned loblolly pine ties.
2. Steam: None.
3. Air pressure: 65 pounds for 30 minutes without releasing for the application of creosote.
4. Creosote at 110° to 115° F. and 100 pounds pressure for 2 hours.
5. Vacuum of 26 inches for $1\frac{3}{4}$ hours.

An average of 13.7 pounds of creosote was absorbed by each tie. The ties were treated in December, shipped to the testing laboratory, and exposed to the air until the following April. The untreated ties no doubt absorbed more moisture, and were greener than the treated ties at the time of test. Test pieces from these were tested in cross bending, compression parallel to grain, compression at right angles to grain, and shear under static loads.

The system described on page 8 was used in taking the test pieces.

The results are shown in Table 9.

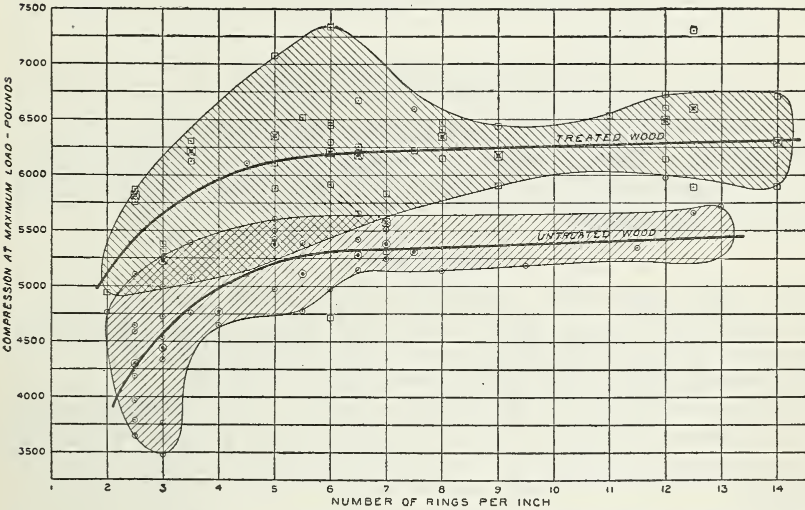

FIG. 2.—Comparative strength of loblolly pine, untreated and creosoted without steaming: Circles represent untreated wood, squares represent treated wood. Large circles and squares show averages of groups. Shaded portions include all but erratic tests.

METHODS OF TEST.

The methods of test were those standard in the Forest Service, which are fully described in Circular 38.[a]

The methods of measurement were precise. Great care was taken to render the results accurate and reliable. No measurements or other data that might be of future value were omitted.

The data taken included the moisture conditions, specific gravity, rate of growth, sap and heart, and in the case of full-sized ties the weight at various stages, the defects, such as knots, checks, crooked grain, rate of growth throughout the cross section, penetration of preservative fluid, discoloration due to steaming, etc. During the cylinder operations at St. Louis records were kept of the temperature to which the timbers were subjected at all stages, the amount of moisture lost or gained, and the amount of preservative absorbed, as indicated by the gross weight and subsequent chemical analysis of the test pieces.

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[a] Instructions to Engineers of Timber Tests, Cir. 38, Forest Service, U. S. Dept. of Agriculture.

The strength of natural and steamed wood was compared upon the basis of both static and impact tests. In the case of green timber the strength tests were ordinarily made immediately after the completion of the cylinder operations. In addition, a set of test pieces was set aside and allowed to become thoroughly air-seasoned in order to determine if any weakness resulting from the cylinder operations would be removed or increased by subsequent seasoning. When the cylinder operations were performed on seasoned ties these were set aside and allowed to return to their original condition of seasoning before they were tested.

In connection with the tests the characteristics of both the natural and the treated specimens were carefully described. In selecting clear test pieces from the ties the treated and control test pieces may not lie end to end. There is also a loss because of culls. Thus in certain cases some disparity in the essential character of the material under comparison will result.

RESULTS.

The results of the tests are shown in Tables 1 to 9 and in figure 2. The six columns to the right of the tables display the comparative quality of the wood in the treated and control specimens.

The strength factors of the treated wood are given in percentages. The mechanical properties of the material under test in its natural condition may be judged from the information given at the bottom of the tables.

It should be noted that the comparisons are based mainly upon the results of static and impact tests in bending and compression parallel to grain. The character and total number of the tests made and the number of each kind are shown in Table 1. The following comments are made in connection with the tables:

VARIABILITY OF MATERIAL.

In order to obtain an indication of the inherent variability of the material used in these tests under the methods described, adjoining sections 3 feet long, taken from each of 4 ties, were compared with one another. (See Table 2.) Four test pieces were taken from each 3-foot section in the manner described on page 8. A comparison of the results of tests upon these pieces is shown in Table 2 and indicates that a difference of average results of as much as 6 per cent may be due to the inherent variability of the material. That is, a difference of 6 per cent between the strength of 2 sets of test pieces, each from 4 ties, one set steamed and the other set not steamed, does not necessarily signify—unless supported by other evidence—that the process has caused the difference in strength. Of course a larger number of comparisons than are given in Table 2 might have shown greater variability. It is a very difficult task to isolate and determine the effect of any one variable in the case of timber, particularly in the case of loblolly pine, since timber must be used as grown and can not be manufactured for experimental purposes. A careful selection serves to minimize the natural differences of quality, but does not remove them. The results of tests on small 2-inch by 2-inch specimens determine the influence of any particular factor under consideration better than tests of full-sized ties. The latter, however, may tell us what significance the results derived from small pieces have in the case of actual material. (See Table 8.)

STRENGTH OF STEAMED WOOD.

In Table 3 the reference numbers 1 to 7 show the increasing loss of strength directly after steaming under increasing pressure (temperature) of the steaming process and reference numbers 8 to 15 show the increasing loss of strength with the increased duration of a given pressure.

The ties were green before treatment. The pieces were tested shortly after being taken from the cylinder and when laden with moisture. In the case of reference number 13 it will be noted that the temperature was less than it should have been, and this fact explains the increased per cent of strength under this reference number. The impact results are erratic.

Under light pressure the weakening shown in Table 3 was not entirely permanent. As shown in Table 4, the wood, when allowed to season after treatment, regained the greater part of its original strength. The Burnettized wood was rendered brittle.

GAIN IN WEIGHT FROM STEAMING.

The steam is allowed to enter the cylinder and come in direct contact with the ties, with the intention that the sap, which contains food for decay-producing fungi, may be removed. A vacuum is then created in the cylinder, and the steam, together with whatever removed contents of the ties there may be, is drawn out of the cylinder. The condensation from the steam when it first meets the ties saturates the cell walls with moisture and renders them pliable and weak. Indeed, the cell walls seem to take up more moisture from the steam than is found in the green wood. A green tie is usually heavier after having been in this steam bath. (See Tables 10 and 11.) Thus in Table 11 it will be seen that up to a pressure of 40 pounds the green ties gained in weight. The indications are that the weight of the partly seasoned ties was increased to a greater extent than the green ties. From 40 pounds pressure the action of the steam was, in cases, to diminish the weight of the tie. The same facts appear from a study of the effect of duration of 20 pounds steam pressure. The ties were increased in weight by steaming up to 10 hours, but at 20 hours the change in weight was negligible.

SCORCHING OF THE WOOD.

As a consequence of excessive temperature conditions, there was, as has been shown, a diminution of the strength of the wood, the amount of which depends, no doubt, upon the species of wood, the degree of seasoning, and also upon the character of growth in the different parts of a tie.

Evidently, since the weakening is due to heat, any cause which protects the tie from the heat will tend to diminish the resulting loss. Thus green ties will no doubt suffer less from the action and the duration of a given pressure than well-seasoned ties. Hard summerwood suffers less than spring wood. Sapwood suffers more than heartwood, which seemed in these experiments not to be affected. The denser the growth, the greater the degree of steaming required to cause weakening.

The effect of the high temperatures upon the wood was sufficient to produce a visible discoloration. A study of the evidence of scorching is given in Table 12, referring to material in Tables 3 and 6, in which 2-inch by 2-inch specimens, taken from the cross sections of the tie about 1 inch from the surface begin to show the discoloration at 40 pounds. and suffer more seriously as the temperature increases. Sixty-four per cent of the disks were discolored at 50 pounds steam pressure, and 94 per cent at 100 pounds steam pressure. Thirty-eight per cent of the disks showed discoloration from five hours of 20 pounds steam pressure, and 100 per cent from twenty hours of 20 pounds steam pressure.

An examination of the wood also disclosed the fact that those ties which were the greenest, and therefore contained the most sap, suffered the least under the action of a given steam pressure or of a given duration of steam pressure. The degree of scorching was in no case so serious as to prevent the wood from showing firmness and hardness under the cutting action of a knife.

An attempt was made to determine the actual temperature inside the ties. Immediately after they were taken from the cylinder a hole was bored in the center and a thermometer inserted. Cotton batting was inserted between the thermometer and the wood at the surface of the tie. The readings showed that when the temperature in the cylinder was 256° F. the temperature inside the green tie was from 200° to 210° F.

Since the green ties did not lose weight in the steaming process at ordinary pressures (see Table 11), the temperature could not have reached the interior of the tie, in spite of the fact that the pressure was kept up for a sufficient period of time to allow the thermometer reading of the temperature surrounding the ties to become constant, for if the water in the ties (under pressure) had attained the temperature of the steam, this water, upon the release of pressure, probably would have turned to steam and found its way out of the wood, or if the vacuum had been suddenly applied, the wood probably would have split under the sudden generation of steam in the ties. The evidence in Tables 2 and 10 to 13 gives support to the opinion that the temperature of the steam did not reach the interior wood of these green ties. Otherwise they would have lost weight and been burnt to a greater extent than that indicated by Tables 11 and 12.

BURNETTIZED TIES.

After the application of a vacuum, the preservative, either zinc chlorid (Burnettizing) or creosote, was forced into the wood under pressure. In Table 3, reference numbers 17 and 18, is given the strength of wood which was steamed and then treated with zinc chlorid, compared with wood which was only steamed. The table shows that the treatment with zinc chlorid did not reduce the resistance of the wood to static loading. Wood steamed and treated with zinc chlorid was weaker under this test than natural wood, but was not weaker than steamed wood. It should be remembered that a difference of 2.1 per cent is not significant. However, under impact loading there is a deficiency of strength in the Burnettized wood.

CREOSOTED TIES.

Table 3, reference number 16, shows that the creosote also did not directly weaken the wood. The steamed and creosoted wood was weaker than the natural wood, but was not weaker than the steamed wood. A microscopic examination of treated wood showed that creosote probably does not enter the substance of the cell walls, but fills the openings of the cells and paints the surfaces. It therefore should not directly weaken the wood. Creosoted wood, however, dries out more slowly than natural wood, because the cells and passageways are full of creosote. Thus creosoted wood will season very slowly, and if two pieces of wood having the same essential structure—one green and natural and the other green and creosoted—were allowed to season, the natural wood would develop increased strength due to the seasoning, while the creosoted wood would not gain in strength so rapidly. This result is shown in Table 4, reference number 5 (static tests), and Table 7, reference number 11. It must be said, however, that large timber rapidly seasoned often develops weaknesses due to checks and shakes, from which creosoted wood may be more or less protected.

The discoloration of the wood due to the presence of creosote will hide the brown or burnt appearance due to excessive steaming.

The presence of creosote in the wood renders it impracticable to determine the amount of moisture in the cell walls. Thus in the accompanying tables the moisture in creosoted wood is not quoted, nor the dry specific gravity of the wood.

According to the tests in Table 9, the wood which has been through the process is stronger than the untreated wood. This is no doubt due either to the effect of the bath of hot oil in seasoning the wood or to the different degrees of subsequent air seasoning of the natural and treated specimens. A difference of 2 per cent in the moisture content of seasoned wood affects the strength by 10 per cent. In the absence of moisture determinations the actual degree of this seasoning can not be given, nor can the moisture be calculated by subtraction of the amount of oil in the wood. The exact amount of oil in the wood can not be obtained from the tank readings, since an unknown per cent of the lighter constituents of the oil will pass off during the application of the vacuum.

SEASONING AFTER STEAMING.

In order to ascertain whether the weakness due to the action of steam was permanent, a set of specimens was laid aside to air dry instead of being treated when wet from the steam. Both control test pieces and treated test pieces were allowed to air dry for eight months. The natural wood, steamed wood, and Burnettized wood reached the same (about 13) per cent of moisture (see Tables 4 and 6), while the creosoted wood certainly did not. Table 4, reference numbers 1 to 4, shows that both the natural wood and steamed wood reached the same strength after having been dried. This wood was, however, of a rather harder and denser growth, and did not disclose the burnt hue referred to (page 14) even after steaming at 50 pounds pressure. The ties were also greener then those in Table 3, and were full of sap.

The conclusion can not be drawn from Table 4 that the weakening due to the steaming is in general only temporary, for this wood had not been affected by the steam like the other green ties. Table 7 (page 19) shows that there was a permanent weakening of the full-sized ties that had been steamed and then allowed to season.

Studies in progress at the timber-testing station of the Forest Service at the Yale Forest School relative to the effect on the strength of wood of various methods of drying under hot air and steam indicate that the action of moist heat is to bring about a change in the structure of the material of the cell walls, whereby these cell walls are able to take up a greater percentage of moisture than in their natural green state. Thus the fiber-saturation point is raised, and the material is softer and more pliable and has less strength. When the walls are dried out by subsequent seasoning they regain the greater part of their strength, provided the steam process has not been excessive. Upon subsequent soaking in water, however, it is evident that the change in structure has been permanent, for the raised fiber-saturation point prevails. The resoaked material shows about 20 per cent less strength than the original green material.

Table 4, reference number 5, shows also that under static tests the specimens that had been steamed and creosoted and then air-dried did not reach the strength of pieces that had been steamed and air-dried. This is no doubt due to the fact that the cell walls did not dry out. As before stated, the presence of the creosote in the wood renders moisture determinations impracticable. Under the impact tests the wood, being pliable, showed greater shock resistance at rupture.

Reference numbers 6 to 9 show that the pieces which had been steamed and treated with zinc chlorid and then air-dried were not weaker under static loading than the pieces which had been steamed and air-dried.

Reference numbers 7 to 9 show that the impact tests disclosed a weakness in the Burnettized wood, which weakness did not appear in the static tests. The greater the amount of zinc chlorid the greater was the decrease in strength. This agrees with the results in Table 3 (reference numbers 17 and 18).

SOAKING AFTER STEAMING AND SEASONING.

Some of the air-dried pieces referred to in Table 4 were resoaked in water to bring them back to the green state and then tested. (Table 5).

The steamed and soaked wood was weaker than the soaked natural wood (reference numbers 1 to 4, Table 5). (See remarks on pages 16 and 17.) The percentage of the strength in Table 5 compared with that in Table 3 at the same steam pressures (reference numbers 3 to 7) suggests what was found by inspection of the wood, namely, that the steam had not affected the wood to the same degree as that shown in Table 3. Table 5, reference numbers 6 to 9, again shows that the zinc chlorid itself had no effect on the strength under static tests.

This table, reference number 5, confirms the reasoning deduced from Table 4 (page 16). The wood which was steamed, creosoted, air-dried, and then resoaked was not weaker than the wood which had been steamed, air-dried, and resoaked. It will be noted from the information at the bottom of Table 5 that the strength of the wood which had been air-dried and resoaked was less than that of the green wood described at the bottom of Table 3. It has been shown in the experiments referred to on page 16 that resoaking after steaming and air-drying lowers the strength of the wood. The difference between Tables 5 and 3 confirms this conclusion. Soaking green wood in water does not, however, lessen its strength.

The foregoing comments relative to the action of the cylinder processes on green wood may be summarized as follows:

(1) The steam at pressures up to 40 pounds applied for 4 hours or at a pressure of 20 pounds up to 20 hours increases the weight of the ties. At 40 pounds pressure applied for 4 hours and at 20 pounds for 5 hours the wood began to be scorched. (See Table 11.)

(2) The steamed and saturated wood when tested immediately after treatment exhibited weakness in proportion to the pressure and duration of steaming. (See Table 3.) If allowed to air-dry subsequently the specimens regained the greater part of their strength, provided the pressure and duration had not exceeded those cited under (1). (See Table 4.) Subsequent immersion in water of the steamed and dried specimens showed that they were weaker than natural wood similarly dried and resoaked. (See Table 5.)

(3) The Burnettized wood was not weaker under static loading than steamed wood, but was weaker under impact. (See Tables 3 and 4.)

(4) The presence of creosote of itself did not affect the strength of the wood. It affected only the rate of seasoning. (See Tables 3, 4, and 5.)

STRENGTH OF SEASONED WOOD DIRECTLY AFTER TREATMENT.

The material of Table 3 was green when treated. In Table 6 the results of tests upon material which was seasoned before treatment and tested directly after treatment are given. The steamed wood shows a large decrease in strength, about 33 per cent at 50 pounds (reference number 2). The wood was of faster growth and had less specific gravity than that described in Table 3. Inspection of the test pieces showed (Table 12) that at 50 pounds pressure all the test pieces had been scorched.

In Table 6, reference number 3, it is again shown that no further diminution of strength beyond that due to steaming occurs in the presence of creosote. The reason that the treatment with cresote, without steam, shows (reference number 4) a reduction in strength is probably because of the presence in the creosote of suspended water which would saturate the cell walls of the creosoted test pieces, whose strength is compared with that of the seasoned but untreated control pieces.

To show more clearly that the action of creosote is only to affect the movement of moisture to or from the cell walls, the control pieces and the creosoted pieces were soaked in water. The table (reference number 5) shows that the control test pieces had less strength than the creosoted test pieces. The conclusion is that cell walls of the control test pieces had taken up their full complement of water, and the walls of the creosoted test pieces had not.

STRENGTH OF SEASONED FULL-SIZE TIES RESEASONED AFTER TREATMENT.

The results quoted heretofore have been based upon tests upon small test pieces taken from loblolly pine ties. A series of 165 seasoned loblolly pine ties was steamed and treated and then allowed to air season until they had reached, with some exceptions, their original weight. (See Table 7.) They were then tested in full size.

Table 7 (reference numbers 1 to 9) shows that these seasoned ties suffered permanently under the steaming. An inspection of the wood showed that the scorched appearance of the tie extended through the sapwood to the heart to the extent indicated by Table 13. The variation in the degree of scorching (as stated on p. 14) is no doubt affected by the character of the growth and other circumstances not yet understood. The results indicate, however, that the temperature of steam will begin to scorch the wood of seasoned loblolly pine ties as follows: At 30 pounds for 4 hours, or at 20 pounds for 6 hours.

The ties that were steamed and then treated with zinc chlorid, Table 7 (reference number 10) showed a less strength than the steamed ties (reference number 2 or 7). However, the ties treated with zinc chlorid had not dried to their original weight at the time of test, and were therefore seasoned to a less degree than the natural ties with which they are compared. (Reference number 10 and bottom of Table 7.) These Burnettized ties were 7.1 pounds heavier per tie than their original weight. Of this one-half pound was zinc chlorid salt.

The ties that were steamed and creosoted (reference number 11) showed less strength than those that were steamed, for the reason that the wood of the walls had not dried out to the same degree.

The spike-holding power was reduced in the case of the ties that were steamed at high pressure. It was also reduced in the creosoted and Burnettized ties treated at low pressures. In the latter cases this diminution was due partly to the greener state of the wood.

Reviewing the evidence presented in Tables 6 and 7, and summarized in Table 10, the following observations may be made with reference to the action of the cylinder processes on seasoned loblolly pine ties:

(1) The steam, at pressures up to 50 pounds for 4 hours and at 20 pounds up to 10 hours, increased the weight of the ties (see Table 10); at 30 pounds for 4 hours or 20 pounds for 6 hours the wood began to be scorched. (See Table 13.)

(2) When tested after subsequent seasoning the ties which had been steamed at and above these pressures showed a decided loss of strength. (See Table 7.)

(3) The Burnettized ties and creosoted ties were weaker than the natural wood and weaker than the steamed wood which had been seasoning for the same length of time. (See Table 7.) They had not, however, seasoned as rapidly.

BRIDGE TIES OF WESTERN YELLOW PINE.

A number of sawed bridge ties of western yellow pine grown in Arizona and New Mexico were treated at St. Louis by various processes and then tested full size after being partially seasoned. (See Table 8.)

The ties were average bridge ties of large inherent variability, so that concordant results were not to be obtained. The New Mexico pine was of straighter grain and contained fewer knots than the Arizona pine, which was of coarse growth, crooked grained, and knotty. The data concerning the wood given below Table 8 illustrate these statements.

In addition to testing the ties in full size, disks were sawed from the cross section to yield small, clear pieces for tests of compression parallel to grain. The resulting values of the crushing strength are listed in Table 8, adjusted to uniform moisture of 12 per cent. The results, though extremely variable, are presented for what they are worth. Attempts to remove apparent contradictions by analysis of the wood have so far proved unsuccessful. It will be noted that the Arizona ties treated with zinc chlorid were of greater strength than the untreated ties, and that the reverse is true of the New Mexico ties. These results in Table 8 illustrate the difficulty which confronts the experimenter in the field of timber tests.

LOBLOLLY PINE TIES CREOSOTED WITHOUT STEAMING.

The process to which these ties were subjected is described on page 11. It will be seen that there was no steaming and that the temperature of the creosote was not such as to harm the wood. Its effect probably was to season it. An increase in strength is thus to be expected. (See Table 9.)

The treatment was given at Somerville, Tex., December 15, 1904. Three-foot sections of the ties for test purposes were shipped to St. Louis and allowed to lie in the open air until February 1, 1905, thoroughly protected from rot. They were then shipped to Lafayette, Ind., and piled closely in the open air until April, when they were sawed into 2 by 2 inch test pieces and tested. The wood was sound and bright. It is thus quite probable that the 3-foot sections of the ties representing the untreated wood took up more moisture from the air than did the treated specimens. Thus the untreated specimens would have, at the time of test, a slightly greater moisture content than the treated specimens. This is another possible explanation of the increased strength of the treated test pieces. The remark must again be made that there is no practical method for the determination of the amount of moisture in the cell walls of the creosoted wood.

The average number of rings per inch was greater in the case of the treated wood than in that of the natural wood. A more detailed analysis, in which specimens of like kind are compared, is given in figure 2. It is there shown that the average of the table is significant.

The conclusions drawn from this figure are:

(1) That the process of itself does not weaken the wood.

(2) That since no steam was used, a degree of seasoning resulted which had the effect of making the wood stronger.

(3) That the increase is not due to the particular treatment given, but could be effected by other nonsteaming processes or by air seasoning.

CONCLUSIONS.

The results of the tests shown in these tables form a body of evidence from which the following general conclusions may be drawn:

(1) A high degree of steaming is injurious to wood in strength and spike-holding power. The degree of steaming at which pronounced harm results will depend upon the quality of the wood and its degree of seasoning, and upon the pressure (temperature) of steam and the duration of its application. For loblolly pine the limit of safety is certainly 30 pounds for 4 hours, or 20 pounds for 6 hours. (Tables 3, 6, and 7.)

(2) The presence of zinc chlorid will not weaken wood under static loading, although the indications are that the wood becomes brittle under impact. (Tables 3 and 4.)

(3) The presence of creosote will not weaken wood of itself. Since apparently it is present only in the openings of the cells, and does not get into the cell walls, its action can only be to retard the seasoning of the wood. (Tables 3, 4, 5, and 6.)

Table 1.—*Number of ties used and tests made in the experiments.*

Table No.	Number of ties.	Number of tests.							
		Static.				Impact.		Spike pulling.	Total.
		Bending.	Compression parallel to grain.	Compression at right angles to grain.	Shearing.	Bending.	Compression parallel to grain.		
2	4	16	16	16	16				64
3	148	532	566	247	461	434	410		2,650
4	36	139	142	132	141	137			691
5	(a)		144						144
6	20	75	77	65	59	72	54		402
7	165	165	120	165				639	1,089
8	97	28	678			69			775
9	10	71	78	76	66				291
Total	480	1,026	1,821	701	743	712	464	639	6,106
Additional									166
Grand total									6,272

[a] Specimens cut from same ties as 4.

TABLE 2.—*Variation in the strength of green loblolly pine.*

[Tests on 2 by 2 inch specimens cut from one 3-foot section, with the results given in percentages of the strength of a piece in an adjoining 3-foot section.]

Strength (static).		Rings per inch.		Moisture.		Specific gravity (dry).	
Bending—Modulus of rupture.	Compression parallel to grain.	Control.	Adjoining.	Control.	Adjoining.	Control.	Adjoining.
Per cent. 93.7	*Per cent.* 102.6	7.5	7.5	*Per cent.* 51.8	*Per cent.* 53.8	0.518	0.506

PHYSICAL CHARACTERISTICS AND AVERAGE STRENGTHS OF THE WOOD.

STATIC LOADING.

Moisture	per cent	51.8
Weight per cubic foot (dry)	pounds	32.36
Rings per inch		7.5
Modulus of elasticity	pounds per square inch	1,654,009
Bending strength at elastic limit	do	4,721
Bending strength at rupture	do	10,330
Compression strength parallel to grain	do	3,944

TABLE 3.—*Effect of steaming and preservative treatments on the strength of green loblolly pine.*

[Specimens, 2 by 2 inches; tested immediately after treatment.]

Treatment.	Cylinder conditions.				Strength.				Rings per inch.[a]		Moisture.[a]		Specific gravity (dry).[a]		Reference No.
	Steaming.				Static.		Impact.								
	Period.	Pressure.	Temperature.	Absorption of preservative.	Bending—Modulus of rupture.	Compression parallel to grain.	Bending—Height of drop causing complete failure.	Average of the three strengths.	Control.	Treated.	Control.	Treated.	Control.	Treated.	
	Hours.	*Lbs. per sq. in.*	° *F.*	*Lbs. per cu. ft.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*			*Per cent.*	*Per cent.*			
					Untreated wood=100 per cent.										
Steam, at various pressures..	4	....	[b]230	....	91.3	79.1	96.4	88.9	7.0	7.5	60.8	49.2	0.490	0.500	1
	4	10	238	....	78.2	93.7	93.3	88.4	6.0	5.0	52.2	37.6	.489	.468	2
	4	20	253	....	83.3	84.2	91.4	86.3	7.0	8.0	32.6	34.3	.518	.513	3
	4	30	269	....	80.4	78.4	89.8	82.9	7.0	6.5	39.8	48.1	.493	.479	4
	4	40	283	....	78.1	74.4	74.0	75.5	7.0	7.0	40.5	42.5	.519	.509	5
	4	50	292	....	75.8	71.5	63.9	70.4	7.0	7.0	41.8	46.2	.531	.508	6
	4	100	337	....	41.4	65.0	55.2	53.9	6.5	7.0	52.3	45.5	.501	.456	7
Steam, for various periods...	1	20	257	....	100.6	98.6	86.7	95.3	6.0	6.5	31.7	39.1	.484	.489	8
	2	20	267	....	88.4	93.0	107.0	96.1	5.5	5.0	54.5	55.9	.474	.490	9
	3	20	260	....	90.0	93.6	84.1	89.2	7.0	6.0	37.1	33.8	.532	.531	10
	4	20	253	....	83.3	84.2	91.4	86.3	7.0	8.0	32.6	34.3	.518	.513	11
	5	20	253	....	85.0	78.1	84.2	82.4	6.0	6.5	38.2	39.3	.506	.509	12
	6	20	242	....	95.2	89.8	76.0	87.0	5.0	6.0	58.9	36.5	.453	.505	13
	10	20	255	....	73.7	82.0	76.0	77.2	6.0	7.0	48.0	47.9	.523	.516	14
	20	20	258	....	67.5	65.0	99.0	77.2	7.0	7.0	61.9	52.8	.523	.508	15
					Steamed wood=100 per cent.										
Creosote, injected at 150° F. under a pressure of 100 pounds per square inch ...	4	20	255	20.02	109.8	108.7	100.4	106.3	7.5	7.0	45.9	....	.523	....	16
Zinc chlorid..................	4	20	249	.50	98.1	107.3	88.4	97.9	6.5	6.0	35.4	108.8	.491	.522	17
	4	20	255	1.75	105.0	112.4	84.2	100.5	5.0	6.0	34.3	106.8	.519	.558	18

[a] Obtained from specimens used in static bending tests.

[b] It will be noted that the temperature was 230°. This is the maximum temperature by the maximum-temperature recording thermometer, and is due to the handling of the exhaust valve. The average temperature was that of exhaust steam.

PHYSICAL CHARACTERISTICS AND AVERAGE STRENGTHS OF THE UNTREATED WOOD.

	Average.	Maximum.	Minimum.		Average.	Maximum.	Minimum.
Moisture ....per cent..	45.7	60.8	32.6	Bending strength at rupture..lbs. per square inch...	9,304	9,888	8,514
Weight per cubic foot (dry) ....pounds..	31.6	33.2	30.6	Compression strength parallel to grain ....do...	4,032	4,366	3,622
Rings per inch	[a] 7	7	6	Compression strength at right angles to grain..do...	605	676	497
Modulus of elasticity ....lbs. per square inch...	1,622,000	1,697,000	1,519,000	Shearing strength radial to grain............do...	940	1,069	834
Bending strength at elastic limit..........do.....	4,863	5,156	4,414				

[a] Rings per inch were measured to the nearest one-half.

TABLE 4.—*Effect of steaming and preservative treatments on the strength of green loblolly pine.*

[Specimens, 2 by 2 inches; air-dried before tests.]

Treatment.	Cylinder conditions.				Strength.				Rings per inch.		Moisture.		Specific gravity (dry).		Reference No.
	Steaming.				Static.		Impact.								
	Period.	Pressure.	Temperature.	Absorption of preservative.	Bending—Modulus of rupture.	Compression parallel to grain.	Bending—Height of drop causing complete failure.	Average of the three strengths.	Control.	Treated.	Control.	Treated.	Control.	Treated.	
	Hours.	*Lbs. per sq. in.*	°*F.*	*Lbs. per cu. ft.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*			*Per cent.*	*Per cent.*			
					Untreated wood=100 per cent.										
Steam, at various pressures..	4	20	257	....	92.8	93.1	93.8	93.2	7.5	6.5	13.8	13.4	0.558	0.546	1
	4	30	273	....	99.8	104.3	102.0	102.0	7.5	7.0	12.7	12.2	.553	.571	2
	4	40	287	....	94.6	99.0	107.7	100.4	6.0	6.0	13.6	12.4	.525	.534	3
	4	50	296	....	94.5	96.4	103.5	98.1	6.5	6.5	13.7	12.5	.514	.508	4
					Steamed wood=100 per cent.										
Creosote, injected at 150° F. under a pressure of 100 pounds per square inch ...	4	20	258	25.4	81.6	79.9	102.4	88.0	6.5	6.0	13.2	....	.553	....	5
Zinc chlorid:															
2.5 per cent solution	4	20	249	....	87.4	92.8	113.8	98.0	6.5	6.0	12.8	13.7	.530	.534	6
3.5 per cent solution.....	4	20	246	....	97.4	95.2	92.7	95.1	7.5	7.0	13.1	13.5	.538	.539	7
5.0 per cent solution.....	4	20	246	....	99.8	96.7	78.9	91.8	5.5	6.0	12.3	13.4	.510	.506	8
10.0 per cent solution....	4	20	255	....	100.1	100.4	74.8	91.8	8.5	8.5	13.2	13.5	.582	.612	9

PHYSICAL CHARACTERISTICS AND AVERAGE STRENGTHS OF THE AIR-DRIED UNTREATED WOOD.

Moisture	per cent..	13.4
Weight per cubic foot (dry)	pounds..	33.6
Rings per inch		7
Modulus of elasticity	lbs. per sq. in..	1,893,000
Bending strength at elastic limit	do....	6,998
Bending strength at rupture	do....	13,198
Compression strength parallel to grain	do....	6,555
Compression strength at right angles to grain	do....	834
Shearing strength radial to grain	do....	1,145

TABLE 5.—*Effect of steaming and preservative treatments on the strength of green loblolly pine.*

[Specimens, 2 by 2 inches; air-dried and resoaked before tests.]

Treatment.	Cylinder conditions.				Strength (static).	Rings per inch.		Moisture.		Specific gravity (dry).		Reference No.
	Steaming.			Absorption of preservative.	Compression parallel to grain.	Control.	Treated.	Control.	Treated.	Control.	Treated.	
	Period.	Pressure.	Temperature.									
	Hours.	*Lbs. per sq. in.*	*°F.*	*Lbs. per cu. ft.*	*Per cent.* Soaked untreated wood=100 per cent.			*Per cent.*	*Per cent.*			
Steam, at various pressures	4	20	257		86.0	7.5	6.5			0.558	0.546	1
	4	30	273		86.6	7.5	7.0			.553	.571	2
	4	40	287		78.5	6.0	6.0			.525	.534	3
	4	50	296		82.0	6.5	6.5			.514	.508	4
					Steamed wood=100 per cent.							
Creosote, injected at 150° F. under a pressure of 100 pounds per square inch	4	20		25.4	106.0	6.5	6.0			.553		5
Zinc chlorid:												
2.5 per cent solution	4	20	249		100.4	6.5	6.0	121.6	122.0	.530	.534	6
3.5 per cent solution	4	20	246		99.0	7.5	7.0			.538	.539	7
5.0 per cent solution	4	20	246		100.0	5.5	6.0			.510	.506	8
10.0 per cent solution	4	20	255		102.0	8.5	8.5			.582	.612	9

PHYSICAL CHARACTERISTICS AND STRENGTH OF THE SOAKED UNTREATED WOOD.

Moisture	per cent	121.6
Weight per cubic foot (dry)	pounds	33.6
Rings per inch		7
Compression strength parallel to grain	pounds per square inch	3,534

TABLE 6.—*Effect of steam and creosote on the strength of seasoned loblolly pine.*

[Specimens, 2 by 2 inches; tested immediately after treatment.]

Treatment.	Cylinder conditions.				Strength.				Rings per inch.		Moisture.		Specific gravity, (dry).		Reference No.
	Steaming.				Static.		Impact.								
	Period.	Pressure.	Temperature.	Absorption of preservative.	Bending—Modulus of rupture.	Compression parallel to grain.	Bending—Height of drop causing complete failure.	Average of the three strengths.	Control.	Treated.	Control.	Treated.	Control.	Treated.	
	Hours.	*Lbs. per sq. in.*	°*F.*	*Lbs. per cu. ft.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*			*Per cent.*	*Per cent.*			
					Seasoned wood=100 per cent.										
Steam, at various pressures.	4		212		92.6	106.4	124.0	107.7	6.0	5.0	20.4	23.1	0.464	0.476	1
	4	50	291		70.9	55.1	72.9	66.3	6.0	6.5	19.0	28.3	.513	.502	2
					Steamed wood=100 per cent.										
Creosote, injected at 150 °F. under a pressure of 100 pounds per square inch	4	20	252	25.62	97.1	102.2	110.7	103.3	7.0	6.5	21.6		.541		3
					Seasoned wood=100 per cent.										
				21.18	81.0	78.4	82.0	80.4	7.5	7.0	18.9		.553		4
					Soaked untreated wood=100 per cent.										
Soaking, wood previously treated with creosote injected at 150 °F. under a pressure of 100 pounds per square inch				19.20	139.4	160.4			6.0	6.5	78.1		.512		5

PHYSICAL CHARACTERISTICS AND AVERAGE STRENGTHS OF THE UNTREATED SEASONED WOOD.

Moisture	per cent.	19.7
Weight per cubic foot (dry)	pounds.	30.48
Rings per inch		6
Modulus of elasticity	pounds per square inch.	1,609,000
Bending strength at elastic limit	do.	5,636
Bending strength at rupture	do.	9,444
Compression strength parallel to grain	do.	4,819
Compression strength at right angles to grain	do.	539
Shearing strength radial to grain	do.	1,069

TABLE 7.—*Effect of steaming and preservative treatments on the strength of seasoned loblolly pine.*

[Specimens, full-sized ties; seasoned, treated, and reseasoned before tests.]

Treatment.	Cylinder conditions.			Strength (static).				Spike pulling.		Rings per inch.	Weight, air-seasoned.	Reference No.
	Steaming.			Bending.	Compression.		Average of the three strengths.	Force required to pull spike.				
	Period.	Pressure.	Temperature.	Modulus of rupture.	Parallel to grain.	At right angles to grain.		Screw.	Common.			
	Hours.	*Lbs. per sq. in.*	*°F.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		*Lbs. per cu. ft.*	
					Untreated wood = 100 per cent.							
Steam, at various pressures	4	10	237	99.2	79.3	91.1	89.9	118.5	110.7	4.9	38.0	1
	4	20	258	93.7	78.4	99.1	90.4	103.6	109.4	5.2	37.3	2
	4	30	274	87.8	83.4	92.7	88.0	100.1	96.5	5.3	37.9	3
	4	40	286	88.4	78.1	74.6	80.4	93.0	77.9	5.2	37.8	4
	4	50	295	69.1	60.6	74.4	68.0	80.4	70.3	4.8	36.1	5
Steam, for various periods	2	20	257	82.4	81.9	87.1	83.8	97.9	93.7	5.1	38.1	6
	4	20	258	93.7	78.4	99.1	90.4	103.6	109.4	5.2	37.3	7
	6	20	256	87.5	78.8	92.0	86.1	83.0	79.0	4.6	36.7	8
	10	20	256	77.0	75.5	73.2	75.2	84.1	76.8	4.8	36.7	9
Zinc chlorid, 2.5 per cent solution	4	20	258	74.7	65.1	68.6	69.5	75.3	73.8	4.3	41.5	10
Creosote, 28 pounds per cubic foot	4	20	257	69.5	61.2	60.1	63.6	68.2	68.1	4.6	65.3	11

PHYSICAL CHARACTERISTICS AND AVERAGE STRENGTHS OF THE UNTREATED WOOD.

Moisture	per cent (approximate)	20.0
Weight per cubic foot (air-seasoned)	pounds	38.4
Rings per inch		5
Modulus of elasticity	pounds per square inch	1,568,000
Bending strength at elastic limit	do	3,429
Bending strength at rupture	do	6,458
Compression strength parallel to grain	do	4,452
Compression strength at right angles to grain (rail bearing)	do	503
Spike pulling—common spike	do	3,598
Spike pulling—screw-spike	do	7,748

TABLE 8.—*Effect of preservative treatments on the strength of western yellow pine.*

[Tested full size; air-dried before testing.]

Treatment.	Ties from—	Cylinder conditions.				Strength.			Rings per inch. [a]		Weight (air-seasoned). [a]		Reference No.
		Steaming.				Static.		Impact.					
		Period.	Pressure.	Temperature.	Absorption of preservative.	Bending—Modulus of rupture.	Compression parallel to grain.	Bending—Height of drop causing complete failure.	Control.	Treated.	Control.	Treated.	
		Hours.	*Lbs. per sq. in.*	°*F.*	*Lbs. per cu. ft.*	*Per cent.*	*Per cent.*	*Per cent.*			*Lbs. per cu. ft.*	*Lbs. per cu. ft.*	
						Untreated wood=100 per cent.							
Zinc chlorid	Arizona				[b] 16.05	138.3	104.3	107.1	14.1	12.1	32.0	35.8	1
		3	20	258	[b] 14.37	120.9	124.2	214.2	14.1	14.6	32.0	39.4	2
	New Mexico				[b] 13.84	79.5	126.2	156.0	12.1	17.2	31.1	36.7	3
		3	20	258	[b] 19.77	61.8	94.6	104.0	12.1	12.6	31.1	47.0	4
Creosote	Arizona				11.34	134.0	104.9	164.3	14.1	12.9	32.0	40.5	5
		3	20	257	17.54	130.6	81.9	100.0	14.1	13.8	32.0	49.0	6
				[c] 220	12.27	142.9	93.5	107.1	14.1	10.1	32.0	44.9	7
				[c] 275	12.78	133.9	97.4	135.8	14.1	11.9	32.0	46.6	8
	New Mexico				10.34	71.5	64.9	104.0	12.1	10.9	31.1	43.5	9
		3	20	257	10.61	71.7	69.3	80.0	12.1	12.7	31.1	42.5	10
				[c] 220	10.21	85.0	83.5	108.0	12.1	15.1	31.1	42.4	11
				[c] 275	10.66	59.0	87.9	92.8	12.1	16.0	31.1	43.3	12

PHYSICAL CHARACTERISTICS AND AVERAGE STRENGTHS OF THE UNTREATED WOOD.

STATIC LOADING—2 TESTS.

Item.	Arizona.	New Mexico.
Moisture ....per cent.	15.9	19.0
Weight per cubic foot (air-seasoned) ....pounds.	26.4	32.0
Rings per inch	18.8	22.0
Modulus of elasticity ....pounds per square inch.	818,000	1,170,000
Bending strength at elastic limit ....do.	2,280	3,438
Bending strength at rupture ....do.	3,020	5,595
Compression strength parallel to grain ....do.	3,720	4,343

IMPACT LOADING—5 TESTS.

Item.	Arizona.	New Mexico.
Moisture ....per cent.	17.2	12.9
Weight per cubic foot (air-seasoned) ....pounds.	32.0	31.1
Rings per inch	14.1	12.1
Modulus of elasticity ....pounds per square inch.	807,000	813,000
Bending strength at elastic limit ....do.	4,296	5,255

[a] Obtained from specimens tested under impact load.

[b] Wet solution.

[c] Boiled in oil.

TABLE 9.—*Effect of creosoting without steam on the strength of seasoned loblolly pine.*

[Specimens, 2 by 2 inches; seasoned, treated, and air-dried before tests.]

Treatment.	Strength (static).		Rings per inch.		Moisture control.	Weight (air-seasoned).	
	Bending—Modulus of rupture.	Compression parallel to grain.	Control.	Treated.		Control.	Treated.
	Per cent. Untreated wood = 100 per cent.	*Per cent.*			*Per cent.*	*Lbs. per cu. ft.*	*Lbs. per cu. ft.*
Creosote	117.0	130.0	5	7	16.1	34.79	38.23

PHYSICAL CHARACTERISTICS AND AVERAGE STRENGTHS OF THE UNTREATED WOOD.

Moisture	per cent	16.1
Weight per cubic foot (dry)	pounds	30
Rings per inch		5
Modulus of elasticity	pounds per square inch	1,356,000
Bending strength at elastic limit	do	4,439
Bending strength at rupture	do	8,760
Compression strength parallel to grain	do	4,956
Compression strength at right angles to grain	do	700
Shearing strength radial to grain	do	1,105

TABLE 10.—*Amount of water and preservatives absorbed by full-sized seasoned loblolly pine ties during the cylinder treatment.*

Treatment.	Cylinder conditions (steaming).		Number of ties.	Weight of full-sized ties (nominal cross-section 6.75 inches to 9.25 inches).			Reference No.
	Period.	Pressure.		Before steaming.	After steaming.	After treatment.	
	Hours.	*Lbs. per sq. in.*		*Pounds.*	*Pounds.*	*Pounds.*	
Steam, at various pressures	4	10	16	132.1	137.2	....	1
	4	20	16	129.5	136.4	....	2
	4	30	16	136.6	142.9	....	3
	4	40	16	140.8	148.9	....	4
	4	50	15	134.8	139.1	....	5
Steam, for various periods	2	20	16	136.6	145.9	....	6
	6	20	15	128.7	139.5	....	7
	10	20	16	128.1	138.8	....	8
Creosote, 28 pounds per cubic foot.	4	20	15	135.7	140.0	237.2	9
Zinc chlorid, 2.5 per cent solution.	4	20	15	141.6	146.2	247.2	10

TABLE 11.—*Amount of water and preservatives absorbed by full-sized green loblolly pine ties during the cylinder treatment.*

Treatment.	No. of series.	No. of run.	Length of tie.	No. of ties.	Commercial seasoning condition.	Cylinder conditions.								Gain per tie.			Reference No.
						Steaming.			Vacuum.		Preservative.						
						Period.	Pressure.	Temperature.[a]	Period.	Pressure.	Period.	Pressure.	Temperature.	After steaming.	After vacuum.	After treatment.	
			Feet.			*Hours.*	*Lbs. per sq. in.*	*°F.*	*Hours.*	*Inches.*	*Hours.*	*Lbs. per sq. in.*	*°F.*	*Pounds.*	*Pounds.*	*Pounds.*	
Steam, at various pressures.	25	46	8	4	Wholly green	4	....	230	....	....	....	....	....	0.00	....	....	1
	26	46	11	4	Partly green	4	....	230	....	....	....	....	....	10.87	....	....	2
	104	95	8	4	Wholly green	4	10	238	....	....	....	....	....	2.13	....	....	3
	7	7	11	4	Green	4	20	253	....	....	....	....	....	6.62	....	....	4
	7	39	11	4	do	4	20	250	....	....	....	....	....	10.87	....	....	5
	37	68	8	4	Partly green	4	20	256	....	....	....	....	....	8.40	....	....	6
	3	3	11	4	Green	4	30	268	....	....	....	....	....	5.70	....	....	7
	3	42	11	4	do	4	30	268	....	....	....	....	....	10.13	....	....	8
	116	80	8	4	Wholly green	4	30	272	....	....	....	....	....	0.62	....	....	9
	4	4	11	4	Green	4	40	286	....	....	....	....	....	4.00	....	....	10
	4	43	11	4	do	4	40	277	....	....	....	....	....	7.75	....	....	11
	117	81	8	4	Wholly green	4	40	285	....	....	....	....	....	[b]1.12	....	....	12
	5	5	11	4	Green	4	50	295	....	....	....	....	....	5.10	....	....	13
	5	45	11	4	Partly green	4	50	291	....	....	....	....	....	8.63	....	....	14
	23	45	8	4	Wholly green	4	50	291	....	....	....	....	....	[b]0.62	....	....	15
	118	82	8	4	do	4	100	337	....	....	....	....	....	[b]7.38	....	....	16
Steam, for various periods.	1	1	11	4	Green	1	20	257	....	....	....	....	....	4.25	....	....	17
	1	68	11	4	Partly green	1	20	258	....	....	....	....	....	8.75	....	....	18
	105	96	8	4	Wholly green	2	20	257	....	....	....	....	....	2.50	....	....	19
	2	2	11	4	Green	3	20	252	....	....	....	....	....	8.50	....	....	20
	2	36	11	4	do	3	20	247	....	....	....	....	....	11.63	....	....	21
	7	7	11	4	do	4	20	253	....	....	....	....	....	6.62	....	....	22
	7	39	11	4	do	4	20	250	....	....	....	....	....	10.87	....	....	23
	37	68	8	4	Partly green	4	20	256	....	....	....	....	....	8.40	....	....	24
	21	40	11	4	Green	5	20	248	....	....	....	....	....	15.50	....	....	25
	21	68	11	4	Partly green	5	20	257	....	....	....	....	....	12.37	....	....	26
	22	41	11	4	Green	6	20	242	....	....	....	....	....	16.75	....	....	27
	6	6	11	4	do	10	20	251	....	....	....	....	....	9.10	....	....	28
	119	94	8	4	Wholly green	10	20	258	....	....	....	....	....	1.00	....	....	29
	121	93	8	4	do	20	20	258	....	....	....	....	....	0.63	....	....	30
Creosote, 20.02 pounds per cubic foot	27	72	11	4	Partly green	4	20	258	2	28	3	100	150	14.75	....	58.12	31
	103	72	11	4	do	4	20	258	2	28	3	100	150	15.25	....	56.00	32
	29	58	8	4	Wholly green	4	20	252	2	27	1	100	150	[b]1.00	[b]3.00	26.12	33
	32	58	8	4	Partly green	4	20	252	2	27	1	100	150	11.25	[b]2.63	47.00	34
Zinc chlorid: 2.5 per cent solution	15	31	11	4	Green	4	20	249	1	28.5	2.5	100	....	10.44	....	67.31	35
10 per cent solution	18	34	11	4	do	4	20	255	$1\frac{11}{12}$	27	2	100	....	11.31	....	65.31	36

[a] Maximum temperature recording thermometer.

[b] Represents a loss.

TABLE 12.—*Discoloration of loblolly pine ties during steaming.*

[Results based on appearance of 2 by 2 inch specimens cut from ties.]

Kind of ties.	Treatment.	Cylinder conditions (steaming).		Number of specimens steamed.	Discolored during steaming.		Reference No.
		Period.	Pressure.		Number	Per cent.	
		Hours.	*Lbs. per sq. in.*				
Green	Steam, at various pressures	4	....	32	....	....	1
		4	10	16	....	....	2
		4	20	39	....	....	3
		4	30	40	....	....	4
		4	40	39	10	26	5
		4	50	36	23	64	6
		4	100	16	15	94	7
	Steam, for various periods	1	20	24	....	....	8
		2	20	16	....	....	9
		3	20	24	....	....	10
		4	20	39	....	....	11
		5	20	32	12	38	12
		6	20	14	4	29	13
		10	20	23	7	30	14
		20	20	16	16	100	15
Seasoned	Steam, at various pressures	4	....	16	....	....	16
		4	50	11	11	100	17

TABLE 13.—*Discoloration of entire cross sections of full-sized seasoned loblolly pine ties during steaming.*

Disks examined.	Cylinder conditions (steaming).			Disks discolored.		Reference No.
	Period.	Pressure.	Temperature.	Number.	Per cent.	
Number.	*Hours.*	*Lbs. per sq. in.*	*°F.*			
12 [a]	....	....	....	....	....	1
12	4	10	237	None.	....	2
16	4	20	258	None.	....	3
13	4	30	274	2	15.4	4
12	4	40	286	6	50.0	5
16	4	50	295	15	94.0	6
17	2	20	257	[b] 2	12.0	7
16	6	20	256	10	62.5	8
12	10	20	256	11	91.7	9

[a] Untreated.

[b] Slight discoloration only.

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